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A MODEL ATMOSPHERE FOR EARTH RESOURCES APPLICATIONS

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1. The following information was obtained from a review of the literature and from a study of the data available for the purpose of this report.

A MODEL ATMOSPHERE FOR EARTH RESOURCES APPLICATIONS

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ABSTRACT

A computer subprogram set is described which permits the use of radiosonde data to provide model atmosphere data for earth resources applications.

A MODEL ATMOSPHERE FOR EARTH RESOURCES APPLICATIONS

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SUMMARY

All earth resources remote-sensing techniques are affected by the atmosphere lying between the target and the sensor. The computer program presented in this report offers a method of numerical use of radiosonde data so that atmospheric effects may be assessed and possibly removed from the signal.

INTRODUCTION

The objectives of the NASA Earth Resources Program are to determine the performance capabilities of various sensors, to discover signature criteria of resources, and to develop new sensors and systems that will eventually enable management of earth resources. To accomplish these objectives, certain absolutes which may be used to evaluate sensing systems and techniques must be established. The laboratory usually offers the best testing environment, but the type of target, the conditions of the path of the signal, and other testing parameters are limited. In general, the laboratory is so restrictive that a successful laboratory test of a remote sensor is necessary but not sufficient to ensure proper operation of the sensor in an application. Therefore, much of the testing is performed in the same environment in which the instrument is expected to operate. Testing under such conditions requires that the data concerning the environment between the instrument platform (e.g., an aircraft or a spacecraft) and the target be as accurate as possible. Thus, determination of the "ground truth" and description of the state of the atmosphere in the path of the electromagnetic signal are necessary.

Remote-sensing techniques are affected by the atmosphere lying between the target and the sensor. The amount of noise introduced into the signal by the interaction between the atmosphere and the signal depends upon the type of sensor, the wavelength employed, and the meteorological conditions prevailing at the time of the experiment. Since the NASA Earth Resources Program remote-sensing effort is in a developmental stage, the effects of this interaction are presently being determined, and hopefully, the model atmosphere for earth resources applications, presented in this paper, will facilitate analyses of such effects.

The computer subprogram set presented in this paper offers a self-consistent method for numerically calculating the state of the atmosphere based on radiosonde

data given in terms of significant levels of pressure, temperature, and temperature-dewpoint depression. After data from the radiosonde closest to an aircraft or spacecraft remote-sensing target have been obtained and after these data have been inserted into the computer subprogram set, a programmer has almost any desirable atmospheric parameter available for use in his computer programs. In particular, the subprogram set described in this paper makes available all the necessary quantities for calculation of infrared and microwave absorption or refraction, or both. However, no attempt has been made in this paper to include atmospheric absorption calculations in the model atmosphere; only the basic atmospheric data necessary for the previously mentioned calculations are provided.

The model atmosphere was written in the FORTRAN V computer language for the Univac 1108 computer. However, the program is also compatible with Control Data Corporation and IBM FORTRAN IV compilers. Copies of the computer cards are available upon request from David E. Pitts, TF8, Manned Spacecraft Center, Houston, Texas 77058.

SYMBOLS

C_{sound}	computer symbol ANS(4), speed of sound, m/sec
d	computer symbol DUM/D1, increment of the slant path from r to r' , cm
e	computer symbol ANS(19), $E(X)$, water-vapor pressure, mbar
e_s	computer symbol ANS(20), $E(X)$, saturation water-vapor pressure, mbar
f_w	computer symbol $F(P, X)$, correction for the departure of the air and water-vapor mixture, from ideal-gas law
g	computer symbol ANS(5), acceleration caused by gravity, $f(Z)$, cm/sec^2
g_o	surface gravity, g at R_e , cm/sec^2
H	computer symbol $H(I)$, geopotential altitude, m
H_a	computer symbol H_A, H_{LOW} , geopotential altitude at A , where $H_a < H_b$, m
H_b	computer symbol H_B , geopotential altitude at B , m
H_p	computer symbol ANS(15), pressure scale height, km
H_ρ	computer symbol ANS(16), density scale height, km

M_i	mass percentage of the ith constituent
m	computer symbol ANS(7), molecular weight of the atmosphere, g/g-mole
m_b	molecular weight at H_b , g/g-mole
m_d	computer symbol XMO, molecular weight of the dry atmosphere, g/g-mole
m_o	computer symbol XMO, molecular weight at the surface, g/g-mole
m_w	molecular weight of water, g/g-mole
n'	computer symbol XN2, refractive index at $r' + (1/2)\Delta Z$
n''	computer symbol XN1, refractive index at $r'' + (1/2)\Delta Z$
n_{STP}	computer symbol ANS(17), refractive index of air at STP
$n(Z)$	computer symbol ANS(18), refractive index of air as a function of λ , T , and P
P	computer symbol ANS(1), atmospheric pressure, mbar
P_a	computer symbol PLOW, atmospheric pressure at H_a , mbar
P_b	computer symbol PHIGH, atmospheric pressure at H_b , mbar
q	computer symbol ANS(13), specific humidity, g/kg
q_s	computer symbol ANS(14), specific humidity at saturation, g/kg
R	computer symbol RO, universal gas constant, 8.31432×10^7 ergs/(mole °K)
R_e	computer symbol RE, mean radius of the earth, 6371.299 km
Rel	computer symbol ANS(12), relative humidity, percent
R_X	computer symbol XS-XL, X-component of $(\overrightarrow{r_{sp}} - \overrightarrow{r_l})$, km
R_Y	computer symbol YS-YL, Y-component of $(\overrightarrow{r_{sp}} - \overrightarrow{r_l})$, km
R_Z	computer symbol HS-HL, Z-component of $(\overrightarrow{r_{sp}} - \overrightarrow{r_l})$, km

r	computer symbol ANS(10), mixing ratio of the water in the atmosphere, g/kg
r'	computer symbol S2, distance to shell $Z + \Delta Z$ on the refracted path, km
r''	computer symbol S1, distance to shell Z on the refracted path, km
r_l'	distance from the center of the earth to a target, km
r_s	computer symbol ANS(11), mixing ratio required for the saturation of water in the atmosphere, g/kg
r_{sp}'	distance from the center of the earth to a spacecraft, km
S	computer symbol S, Sutherland's constant, 110.4 °K
s	distance
T	computer symbol ANS(2), kinetic atmospheric temperature, °K
T^*	computer symbol ANS(6), virtual temperature, °K
T_a	computer symbol T(), temperature at H_a , °K
T_a^*	computer symbol TVLOW, virtual temperature at H_a , °K
T_b	computer symbol ANS(2), temperature at H_b , °K
T_b^*	computer symbol TVHIGH, virtual temperature at H_b , °K
T_d	dewpoint temperature, °K
$T_{d,a}$	computer symbol TD(), dewpoint temperature at H_a , °K
$T_{d,b}$	computer symbol ANS(9), dewpoint temperature at H_b , °K
T_m	molecular scale temperature, °K
TOS	computer symbol TOS, angle between r_l' and r_{sp}' , rad
t	time
VV	identifier of the significant-level data set of radiosonde code
Z	computer symbol Z, geometric altitude, km

Z_1	computer symbol ZL, altitude of a target above the earth, km
Z_{sp}	computer symbol ZS, altitude of a spacecraft above the earth, km
β	computer symbol BETA, 1.458×10^{-6} kg/(sec °K m)
γ	ratio of specific heats
ζ	computer symbol PHI, angle from the zenith down to the tangent to the path at the target, rad
ζ''	computer symbol C(3), distance upward from a local station to a spacecraft, rad
η''	computer symbol C(2), distance eastward from a local station to a spacecraft, rad
θ_1	computer symbol THETAL, target longitude, input card, deg (internally, rad)
θ_{sp}	computer symbol THETAS, spacecraft longitude, input card, deg (internally, rad)
λ	computer symbol XLAMDA, wavelength, microns
μ	computer symbol ANS(8), coefficient of viscosity, kg/(msec)
ξ	computer symbol SUM1, dummy variable, rad
ξ''	computer symbol C(1), distance southward from a local station to a spacecraft, rad
ρ	computer symbol ANS(3), atmospheric density, g/cm ³
ρ_d	density of dry air, g/cm ³
ρ_w	density of water vapor, g/cm ³
ϕ'	computer symbol PHIPR, angle between r' and the path of the ray after refraction, rad
ϕ''	computer symbol PHI, angle between r'' and d , rad
ϕ_1	computer symbol PHIL, target latitude, input card, deg (internally, rad)

- ϕ_{sp} computer symbol PHIS, spacecraft latitude, input card, deg (internally, rad)
- ψ computer symbol PSI, angle between r' and d , rad

MODEL ATMOSPHERES

Model atmospheres for earth resources applications may be described as one of three types: preflight, flight, and postflight. Preflight model atmospheres include those which have been developed from aerospace flight-support models (refs. 1 and 2) and statistical models of cloud cover over the earth (ref. 3). The last of these indicates the probability of success on spacecraft- or aircraft-borne photographic missions for earth resources applications.

Flight model atmospheres are calculated from sounding-type remote-sensing devices aboard spacecraft or aircraft. Flight model atmospheres are not presently well developed, but when they are well developed, they will represent the ultimate in knowledge of the "air truth" until special-purpose instruments that will perform atmospheric noise extraction in real time are developed.

Postflight model atmospheres are based upon standard meteorological soundings and are used to assist in the development of flight model atmospheres. These postflight model atmospheres may be described as predictive and nonpredictive.

Predictive postflight model atmospheres use equations of motion, thermodynamics, and continuity and standard meteorological soundings to predict (in time and space) the state of the atmosphere near the target for a remote sensor mounted on an instrument platform. This type of model atmosphere is not presently well developed. Non-predictive postflight model atmospheres offer a self-consistent method of calculating a model atmosphere at the position of a radiosonde which may be located near the experiment platform. The subprogram model atmosphere set discussed in this paper has the capability of performing either as a nonpredictive postflight model atmosphere or as a preflight model atmosphere, depending on the form of the input data.

EQUATIONS FOR THE MODEL ATMOSPHERE

The model atmosphere may generally be considered to be in a state of quasi-static equilibrium. That is, when the equations of motion, thermodynamics, and continuity are scaled and when closed sets are found, the large-scale (i.e., the first order) vertical-component solution will show that, except near clouds with high-velocity updrafts, the hydrostatic equation

$$\frac{\partial P}{\partial Z} = -\rho g \quad (1)$$

applies well. In equation (1), P is atmospheric pressure, Z is geometric altitude, ρ is atmospheric density, and g is the acceleration caused by gravity. At pressures and temperatures experienced in the atmosphere of the earth, the ideal-gas law is usually accurate to within 1 percent. The equation of state

$$\rho = \frac{Pm}{RT} \quad (2)$$

is a form of the ideal-gas law, where m is the molecular weight of the atmosphere, R is the universal gas constant, and T is the kinetic atmospheric temperature.

With certain reasonable and valid assumptions, the proper combination of the hydrostatic equation (eq. (1)) and the ideal-gas law (eq. (2)) results in equations (3) and (4), which are derived in detail in reference 4. If $\partial T^*/\partial H \neq 0$, where T^* is virtual temperature and H is the geopotential altitude, then

$$P_b = P_a \left(\frac{T_b^*}{T_a^*} \right)^{g_o m_d / [R(\partial T^*/\partial H)]} \quad (3)$$

and if $\partial T^*/\partial H = 0$, then

$$P_b = P_a \exp \left[\frac{-g_o m_d (H_b - H_a)}{RT_a^*} \right] \quad (4)$$

In equations (3) and (4), P_b is the atmospheric pressure at H_b , P_a is the atmospheric pressure at H_a , T_b^* is the virtual temperature at H_b , T_a^* is the virtual temperature at H_a , g_o is the surface gravity, m_d is the molecular weight of the dry atmosphere, H_a is the geopotential altitude at A, and H_b is the geopotential altitude at B. In the upper atmosphere, a fictitious temperature designated as molecular scale temperature T_m is defined in order to include variations in molecular weight (caused by molecular dissociation) and temperature in one variable.

$$T_m = T \frac{m_o}{m} \quad (5)$$

where m_o is the molecular weight at the surface. Similarly, in the lower atmosphere, a quantity designated as virtual temperature T^* is defined in order to include variations in molecular weight (caused by water vapor) and temperature in one variable.

$$T^* = T \frac{m_d}{m} \quad (6)$$

Therefore, T^* and T_m may be used interchangeably in equations (3) and (4); this fact enables the use of equations (3) and (4), which were derived for planetary atmospheres in reference 4.

As shown in appendix A, the proper combination of the equation of the state of dry air, the equation of the state of moist air, and equation (6) gives the exact expression of T^* as a function of temperature, pressure, and water-vapor pressure.

$$T^* = \frac{T}{\left(1 - 0.37803 \frac{f_w e}{P}\right)} \quad (7)$$

where f_w is the correction factor for the departure of the air and water-vapor mixture (from the ideal-gas law) and e is water-vapor pressure. Equations (3) and (4), which are the fundamental equations of subroutine MODATM calculations, are used in different forms to find the altitude of the significant levels and to find the pressure at a level between significant levels.

Subroutine MODATM

When atmospheric data at a particular altitude are desired, either geometric altitude is used as the calling variable, or pressure is used as the calling variable and a corresponding geometric altitude is calculated by using equations (3) and (4). Geopotential altitude H is calculated by

$$H = \frac{Z(R_e)}{R_e + Z} \quad (8)$$

where R_e is the mean radius of the earth. Geopotential altitude is then used to calculate temperature, virtual temperature, and molecular weight.

Temperature is calculated by

$$T_b = T_a + \frac{\partial T}{\partial H} (H_b - H_a) \quad (9)$$

where T_b is the temperature at H_b , and T_a is the temperature at H_a . Virtual temperature is calculated by

$$T_b^* = T_a^* + \frac{\partial T^*}{\partial H} (H_b - H_a) \quad (10)$$

Molecular weight is calculated by

$$m_b = \frac{m_d T_b}{T_b^*} \quad (11)$$

where m_b is the molecular weight at H_b .

When P and T^* are known, a form of the equation of state (eq. (2))

$$\rho = \frac{P m_d}{R T^*} \quad (12)$$

is used to calculate density. Then, additional quantities related to altitude, pressure, density, molecular weight, temperature, and virtual temperature are calculated. The equations for the speed of sound C_{sound} , acceleration of gravity g , coefficient of viscosity μ , saturation mixing ratio r_s , saturation specific humidity q_s , pressure scale height H_p , and density scale height H_ρ are as follows:

$$C_{\text{sound}} = \sqrt{\gamma \frac{R T^*}{m_d}} \quad (13)$$

$$g = g_0 \left(\frac{R_e}{R_e + Z} \right)^2 \quad (14)$$

$$\mu = \frac{\beta T^{3/2}}{T + S} \quad (15)$$

$$r_s = \frac{0.62197 f_w e_s}{(P - f_w e_s)} \quad (16)$$

$$q_s = \frac{0.62197 f_w e_s}{(P - 0.37803 f_w e_s)} \quad (17)$$

$$H_p = \frac{RT^*}{m_d g} \quad (18)$$

$$H_\rho = \frac{1}{\frac{1}{H_p} + \frac{1}{T^*} \left(\frac{\partial T^*}{\partial Z} \right)} \quad (19)$$

where γ is the ratio of specific heats, β is 1.458×10^{-6} , S is Sutherland's constant, and e_s is the saturation water-vapor pressure. Equations (13), (15), (18), and (19) are derived in reference 1, equation (14) is derived in reference 4, and equations (16) and (17) are derived in reference 5. The f_w -factor is calculated by a function subprogram simulating tables 89 and 90 given in reference 6.

For calculations of variables describing the amount of water vapor in the atmosphere, dewpoint temperature T_d is calculated as follows:

$$T_{d,b} = T_{d,a} + \frac{\partial T_d}{\partial H} (H_b - H_a) \quad (20)$$

where $T_{d,b}$ is the dewpoint temperature at H_b , and $T_{d,a}$ is the dewpoint temperature at H_a . The equilibrium vapor pressure over a plane surface of water (ref. 6) is then calculated.

$$e = 1013.246 \times 10^{-7.90298 \left[-1.0 + (373.16/T_d) \right] + 5.02808 \log_{10} (373.16/T_d) - 1.3816 \times 10^{-7} \left\{ \frac{11.344 \left[1.0 - (T_d/373.16) \right]}{-1.0 \left\{ 4.8.1328 \times 10^{-3} \right\} \frac{-3.4914 \left[-1.0 + (373.16/T_d) \right]}{-1.0} \right\}} \quad (21)$$

The formula for the vapor pressure over ice (ref. 6) may also be used.

$$e = 6.1071 \times 10^{-9.09718 \left[-1.0 + (273.16/T_d) \right] - 3.56654 \log_{10} (273.16/T_d) + 0.876793 \left[1.0 - (T_d/273.16) \right]} \quad (22)$$

The choice of the temperature ranges during which each of the previously mentioned equations for e is used is determined by the programmer (function E(X)). As presently set up, only equation (21) is used. Equations (21) and (22) are used for calculating e_s by using T in place of T_d .

With the previously discussed basic quantities available, the remaining atmospheric quantities may be calculated. The equations for the mixing ratio r , relative humidity Rel , specific humidity q , refractive index n_{STP} (in wavelength), and refractive index $n(Z)$ (in P , T , and wavelength) are as follows (ref. 5):

$$r = \frac{0.62197 f_w e}{(P - f_w e)} \quad (23)$$

$$Rel = \frac{r}{r_s} \times 100 \quad (24)$$

$$q = \frac{0.62197 f_w e}{(P - 0.37803 f_w e)} \quad (25)$$

For the infrared region (ref. 7)

$$n_{\text{STP}} = 1 + 10^{-8} \left(6432.8 + \frac{2949810.0}{146 - \frac{1}{\lambda^2}} + \frac{25540}{41 - \frac{1}{\lambda^2}} \right) \quad (26)$$

and

$$n(Z) = 1 + (n_{\text{STP}} - 1) \left(\frac{1 + \frac{288.15}{273.16}}{1 + \frac{T}{273.16}} \right) \frac{P}{1013.25} \quad (27)$$

where λ is wavelength. If the wavelength is in the microwave region ($\lambda > 12\,500$ microns, i.e., $\lambda > 1.25$ centimeters), then

$$n(Z) = 1.0 + \left[1.0 \times 10^{-6} \left(77.6 \frac{P}{T} \right) \right] + 373000.0 \frac{e}{T^2} \quad (28)$$

as shown in reference 8.

The input variables of MODATM are included in the calling argument, and all output variables (i.e., the variables calculated by equations (3) to (28)) are stored in a "common block" in the array ANS. Detailed instructions on the use of subroutine MODATM are included in comment cards. For data-card information, see the discussion on subroutine INPUT in this report.

Subroutine INPUT

The purpose of subroutine INPUT is to read the input data cards necessary to set up the significant levels of various atmospheric parameters (i.e., altitude, pressure, temperature, and dewpoint temperature) for subroutine MODATM. Subroutine INPUT is initiated by MODATM whenever pressure (i.e., ANS(1)) is set equal to a number which is less than zero, and because of this fact, many sets of radiosonde data may be used successively, but not concurrently.

The input data may be of the form given in the significant levels (i.e., VV) of pressure, temperature, and temperature-dewpoint depression for a radiosonde. Table I shows an example of radiosonde data and the key to the radiosonde code. Table II gives the input data cards for the example shown in table I.

Subroutine INPUT is also constructed to accept input data other than radiosonde code VV. If the first data card encountered is blank, then each of the next data cards

will be read in uncoded form (i.e., as altitude, temperature, and relative humidity). An example of the input data cards necessary to set up the 15° N annual model (ref. 2) is included in table III.

Levels of possible condensation are indicated by the word "condensation" in the print-out of the significant levels. This occurrence is determined by $T - T_d < 2^\circ \text{ K}$ at 1500 meters and $T - T_d < 8^\circ \text{ K}$ at 9000 meters, which is expressed by the approximate expression

$$T - T_d < 1.0 + 0.000777H \text{ (meters)} \quad (29)$$

Subroutine REFRAC

Subroutine REFRAC is included to assist in making refracted path calculations throughout the atmosphere. The basic equations are developed (ref. 9) from Snell's law

$$n' \sin \phi' = n'' \sin \psi \quad (30)$$

and from the law of sines

$$\frac{\sin \phi''}{r'} = \frac{\sin \psi}{r''} \quad (31)$$

as shown in figure 1. In equations (30) and (31), n' is the refractive index at $r' + (1/2)\Delta Z$, ϕ' is the angle between r' and the path of the ray after refraction, n'' is the refractive index at $r'' + (1/2)\Delta Z$, ψ is the angle between r' and d , ϕ'' is the angle between r'' and d , r' is the distance to shell $Z + \Delta Z$ on the refracted path, and r'' is the distance to shell Z on the refracted path.

The combination of equations (30) and (31) gives

$$\phi' = \sin^{-1} \left(\frac{n'' r'' \sin \phi''}{n' r'} \right) \quad (32)$$

and

$$\psi = \sin^{-1} \left(\frac{r'' \sin \phi''}{r'} \right) \quad (33)$$

Thus, by using known values for r'' , r' , λ , and ϕ'' and by initiating MODATM to obtain values for n'' and n' , the angles ϕ' and ψ are calculated. If a continuous path is desired, ϕ'' should be set equal to ϕ' , and r'' and r' should be incremented. Then, subroutine REFRAC should be called again.

Slant-path calculations are also made available by using the law of sines to calculate the increment d of the slant path from r to r' as follows:

$$d = \frac{r'' \sin(\phi'' - \psi)}{\sin \psi} \quad (34)$$

Since subroutine MODATM is called by subroutine REFRAC and since subroutine MODATM is called last for the altitude corresponding to the middle of d , the array ANS may be used externally to calculate the amount of water vapor or the total atmospheric mass that was traversed over distance d . For the initial calculation at the target point, the angle ξ (i.e., ϕ'') is needed; therefore, subroutine PATH is provided to calculate ξ for the programmer.

Subroutine PATH

The principal purpose of subroutine PATH is to calculate the angle ξ ; however, while calculating ξ , it is also convenient to calculate the columnar mass and the precipitable water vapor along this path. These three quantities are stored in the array ANS. If subroutine PATH is called prior to the calling of subroutine MODATM, ANS(1) will be set equal to -1.0, and subroutine MODATM will be called such that subroutine INPUT is activated, eliminating the future need to call subroutine INPUT externally. Subroutine PATH is thus programed to be called only once for each radiosonde sounding.

The initial guess at ξ is calculated by finding $(\overrightarrow{r_{sp}} - \overrightarrow{r_1})$, the vector from the target (1) to the spacecraft (sp), as shown in figure 2 and as developed in reference 10. The components of $(\overrightarrow{r_{sp}} - \overrightarrow{r_1})$ are

$$R_X = (R_e + Z_{sp}) \cos \theta_{sp} \cos \phi_{sp} - (R_e + Z_1) \cos \theta_1 \cos \phi_1 \quad (35)$$

$$R_Y = (R_e + Z_{sp}) \sin \theta_{sp} \cos \phi_{sp} - (R_e + Z_1) \sin \theta_1 \cos \phi_1 \quad (36)$$

and

$$R_Z = (R_e + Z_{sp}) \sin \phi_{sp} - (R_e + Z_1) \sin \phi_1 \quad (37)$$

where θ_{sp} is the longitude of the spacecraft, θ_1 is the longitude of the target, ϕ_1 is the latitude of the target, ϕ_{sp} is the latitude of the spacecraft, Z_{sp} is the altitude of a spacecraft above the earth, and Z_1 is the altitude of the target above the earth.

The components (R_X , R_Y , and R_Z) are found by coordinate transformation in the coordinate system of the target to be ξ'' , η'' , and ζ'' , which are the respective distances southward, eastward, and upward from a local station to the target.

$$\begin{bmatrix} \xi'' \\ \eta'' \\ \zeta'' \end{bmatrix} = \begin{bmatrix} \sin \phi_1 \cos \theta_1 & \sin \phi_1 \sin \theta_1 & -\cos \phi_1 \\ -\sin \theta_1 & \cos \theta_1 & 0 \\ \cos \phi_1 \cos \theta_1 & \cos \phi_1 \sin \theta_1 & \sin \phi_1 \end{bmatrix} \begin{bmatrix} R_X \\ R_Y \\ R_Z \end{bmatrix} \quad (38)$$

The unrefracted zenith angle

$$\zeta = \tan^{-1} \left[\frac{\sqrt{(\xi'')^2 + (\eta'')^2}}{\zeta''} \right] \quad (39)$$

can then be found. Next, the angle TOS between r_1' and r_{sp}' is calculated by using the definition of the dot product

$$\text{TOS} = \cos^{-1} \left(\frac{\vec{r}_1' \cdot \vec{r}_{sp}'}{|\vec{r}_{sp}'| \cdot |\vec{r}_1'|} \right) \quad (40)$$

so that the best refracted path from the target to the spacecraft (fig. 1) may be found by iteration.

Iteration of paths from the equations developed in the description of subroutine REFRAC is used to find ϕ' and ψ for each level, and since

$$\Delta \xi = \phi'' - \psi \quad (41)$$

integration proceeds until

$$\sum \Delta Z = Z_{sp} - Z_1 \quad (42)$$

Then, $\sum \Delta \xi$ is compared to TOS for the purpose of iterating on ξ as follows

$$\xi(t + \Delta t) = \xi(t) - \frac{(\sum \Delta \xi - \text{TOS})}{2} \quad (43)$$

until $|\sum \Delta \xi - \text{TOS}| \leq 0.0001$ radian (0.0057°). This procedure yields an accuracy on ξ of approximately 3×10^{-3} radian (0.17°). The quantities columnar mass and precipitable centimeters of water along this refracted path are calculated, respectively, in the following equations.

$$\int_{r_1'}^{r_{sp}'} \rho \, ds \approx \sum \rho \cdot d \quad (44)$$

and

$$\int_{r_1'}^{r_{sp}'} q \rho \, ds \approx \sum q \rho d \quad (45)$$

The increments on ΔZ are made to be multiples of 10 smaller than $Z_{sp} - Z_1$, such that

$$Z_{sp} - Z_1 = \Delta Z \cdot i \quad (46)$$

where i is 10, 100, 1000, et cetera and $\Delta Z \leq 0.2$ kilometer.

Subroutine ATMOS3

The subroutine ATMOS3 reproduces the U.S. Standard Atmosphere, 1962 (ref. 1). Subroutine ATMOS3 is called with geometric altitude from which geopotential altitude is calculated. The equations which are subsequently used for ATMOS3 are many of those developed for subroutine MODATM. Equations (3) to (5) and (8) to (15) are common to both subroutines. The main difference between subroutines ATMOS3 and MODATM is that in subroutine ATMOS3, all the significant levels are included in a data statement so that no data cards are necessary, and the output variables are more limited; that is, only the first eight variables in array ANS are available. These variables are pressure, temperature, density, speed of sound, acceleration of gravity, molecular scale temperature, molecular weight, and coefficient of

viscosity. The main purpose for including subroutine ATMOS3 is that if atmospheric data above the maximum-altitude radiosonde data are required of subroutine MODATM, then ATMOS3 is automatically called. The main impact subroutine ATMOS3 has on analyses is that if the maximum usable radiosonde altitude is <10 kilometers, significant water vapor will be ignored since the subroutine ATMOS3 includes no water vapor. Instructions on the use of subroutine ATMOS3 are included in comment cards in the subprogram. The computer print-out, including all subroutines, is shown in appendix B.

CONCLUDING REMARKS

It is hoped that this nonpredictive model atmosphere for earth resources applications will fill the need for atmospheric data until predictive postflight or flight models can be developed.

Manned Spacecraft Center

National Aeronautics and Space Administration

Houston, Texas, November 15, 1969

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TABLE I. - LAKE CHARLES, LOUISIANA, RADIOSONDE AND CODE^a

May 10 1969 0000Z

TT 60004 72240 99016 23266 01008 00146 21467 00512 85517
08463 35017 70118 04273 32033 50577 13571 29543 40743 26569
27572 30946 38567 27590 20217 519// 15400 589// 10650 673//
88999
66280 27595ø

VV 6000/ 72240 00016 23266 11970 18068 22831 06662 33813
11075 44609 02171 55400 26569 66290 40166 77243 461// 88227
451// 99193 535// 11100 673// 31313 25069 451// /////ø

QQ 60000 72240 90012 01008 35512 35007 90346 36009 36013 34524
90789 33530 34031 33031 91246 31535 32539 31534 9205/ 29044
27582 9302/ 27588 27595ø

2nd Trans

WW 6000/ 72240 70866 661// 50071 633// 30391 551// 20653
497// 10115 411// 07358 403//
88950 681// /////
77999ø

YY 6000/ 72240 11950 681// 22920 657// 33600 665// 44230
511// 55100 411// 66070 403//ø

LL 60000 72240 XMTDø

^aThe significant level code is VV. For VV, the code is
iipp TTTdd where

ii = identifier of a set of data; the two characters are
identical (e. g., 00, 11, 22, 33).

ppp = pressure in mbar except the 4th character from the
right is suppressed (e. g., 970 = 970 mbar, and
016 = 1016 mbar).

TTT = temperature, + if last digit is even, and - if last digit
is odd.

dd = dewpoint temperature. If 00-49, multiply by 0.1 for
°C; 50 = 5.0° C; 51-55, not used; 56-99, subtract
50 for °C.

That is, 02 = 0.2, 56 = 6.0, 60 = 10.)

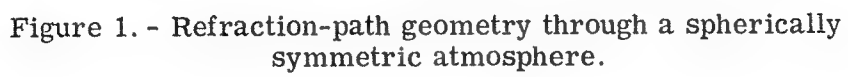
Slashes indicate no data.

RADIOSONDE DATA

FORTRAN

TABLE III. - INPUT DATA CARD FORMAT FOR 15° N ANNUAL
MODEL ATMOSPHERE

STATEMENT NUMBER		CONTINUATION		FOR TRAN	
LOCATION		OPERATION		VARIABLE FIELD	
2	3	4	5	6	7
0	.000E+	00	1.013250E+03	299.65	75
1	.000E+	03	9.039000E+02	293.65	75
2	.000E+	03	8.043000E+02	287.65	75
2	.250E+	03	7.809000E+02	286.15	75
2	.500E+	03	7.580000E+02	286.95	35
4	.000E+	03	6.323000E+02	276.90	35
6	.000E+	03	4.911000E+02	263.50	35
8	.000E+	03	3.764000E+02	250.10	30
1	.000E+	04	2.843000E+02	236.70	20
			-.100000E-05		



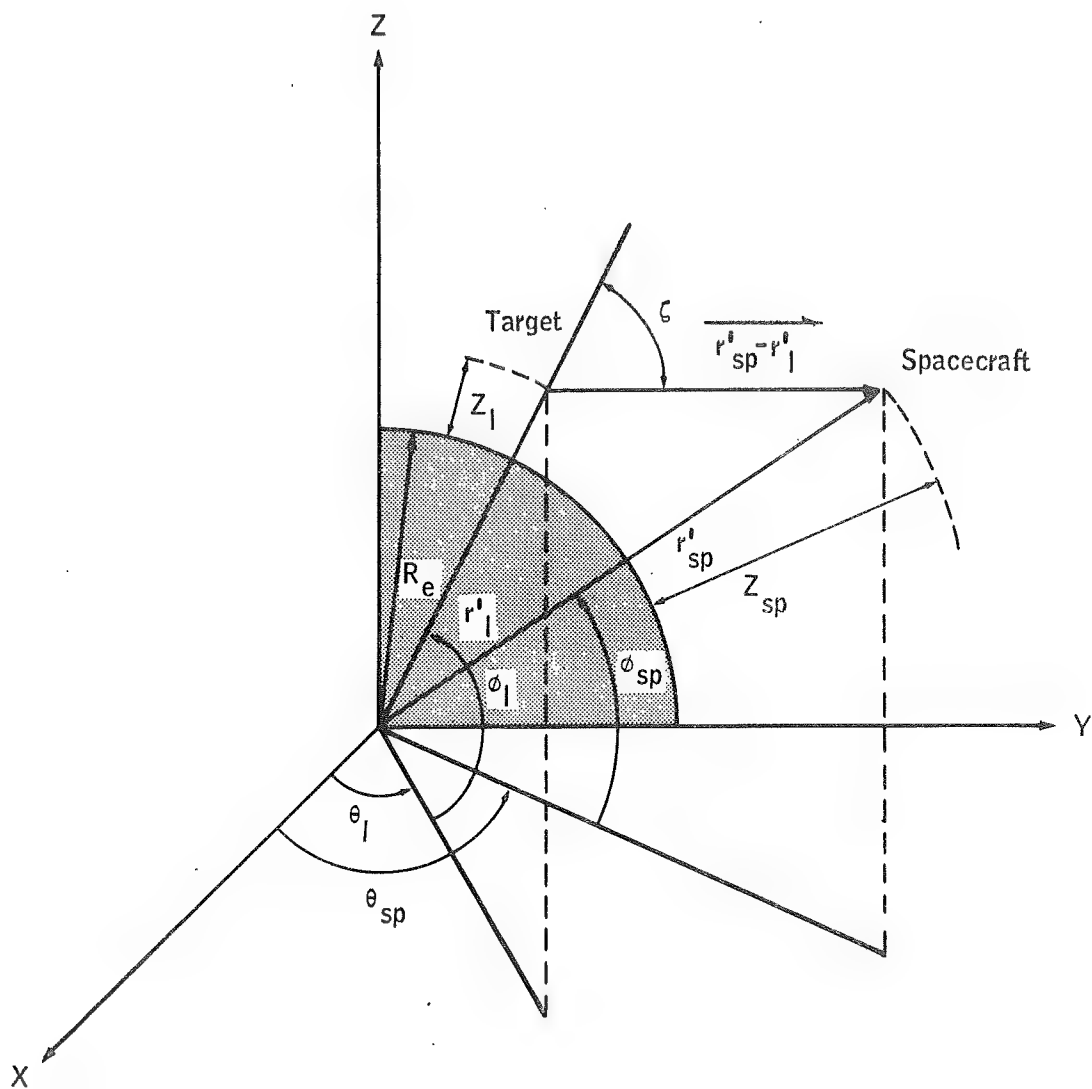


Figure 2. - Resultant vector from the target to the spacecraft in fixed-earth center coordinates.

APPENDIX A

DERIVATION OF VIRTUAL TEMPERATURE T^*

The equations of the state of dry air

$$\rho_d = \frac{(P - f_w e) m_d}{RT} \quad (A1)$$

of water vapor

$$\rho_w = \frac{f_w e m_w}{RT} \quad (A2)$$

and of wet air

$$\rho = \rho_d + \rho_w = \frac{f_w e m_w}{RT} + \frac{(P - f_w e) m_d}{RT} \quad (A3)$$

can be used with the mass percentage formula for molecular weight

$$m = \frac{100}{\sum_i \frac{M_i}{m_i}} = \frac{\rho}{\frac{\rho_w}{m_w} + \frac{\rho_d}{m_d}} \quad (A4)$$

to give a formula for the relationship of temperature, molecular weight, pressure, and water-vapor pressure

$$m = \frac{\frac{f_w e m_w + (P - f_w e) m_d}{RT}}{\frac{f_w e + (P - f_w e)}{RT}} \quad (A5)$$

Equation (A5), when simplified, becomes

$$m = m_d \left[\frac{P + f_w e \left(\frac{m_w}{m_d} - 1 \right)}{P} \right] = m_d \left(1 - 0.37803 \frac{f_w e}{P} \right) \quad (A6)$$

By employing the definition of T^*

$$T^* = \frac{m_d T}{m} \quad (A7)$$

and by using equation (A6), the exact expression for T^* may be found in terms of T , e , and P

$$T^* = \frac{T}{\left(1 - 0.37803 \frac{f_w e}{P} \right)} \quad (A8)$$

APPENDIX B

SUBROUTINES

00101	1*	SUBROUTINE MODATH (Z,PP,TEST,XLAMDA)
00103	2*	DIMENSION H(25),P(25),T(25),TD(25),ANS(35),TV(25)
00104	3*	COMMON ANS
00105	4*	DATA RO/8.31432E+07/,XMO/28.9664/,BETA/1.458E-06/,S/110.4/,RE/6.37
00105	5*	11299E+03/,G/980.665/,CONN/3.41631947E-02/
00105	6*	C
00105	7*	C*****
00105	8*	C
00105	9*	C Z IS IN KM, PP IS IN MB
00105	10*	C ANS IS OUTPUT VARIABLES
00105	11*	C XLAMDA IS THE WAVELENGTH IN MICRONS FOR WHICH YOU ARE CALCULATING
00105	12*	C ATMOSPHERIC REFRACTION
00105	13*	C IF TEST .EQ. PRES THEN PRESSURE IS USED AS HEIGHT INDICATOR
00105	14*	C IF TEST .NE. PRES THEN GEOMETRIC ALTITUDE (KM) IS HEIGHT INDICATOR
00105	15*	C YOU MUST SET ANS(1)=-1.0 BEFORE ENTERING THE SUBROUTINE THE FIRST TIME
00105	16*	C RO IS THE UNIVERSAL GAS CONSTANT BASED ON THE CARBON 12 ATOMIC WEIGHT
00105	17*	C SCALE IN ERGS/(DEG KELVIN*GM-MOLE)
00105	18*	C XMO IS MOLECULAR WEIGHT OF AIR CALCULATED FROM THE COMPOSITION OF DRY
00105	19*	C AIR USING THE CARBON 12 ATOMIC WEIGHT SCALE, FOUND IN THE U. S.
00105	20*	C STANDARD ATMOSPHERE 1962, PAGE 9. GIVEN IN GM/(GM-MOLE)
00105	21*	C BETA IS A CONSTANT USED IN SUTHERLAND'S VISCOSITY EQUATION, GIVEN IN
00105	22*	C KG/SEC-M-(DEG KELVIN**1/2)
00105	23*	C S IS SUTHERLAND'S CONSTANT IN DEG. KELVIN
00105	24*	C RE = THE MEAN RADIUS OF THE EARTH IN METERS AS GIVEN BY THE SMITHSONIAN
00105	25*	C METEOROLOGICAL TABLES, SIXTH EDITION, PUBLICATION 4014, R. J.
00105	26*	C LIST, 1966
00105	27*	C G IS ACCELERATION OF GRAVITY AT 0 EQUIPOTENTIAL SURFACE LEVEL GIVEN IN
00105	28*	C CM/SEC**2
00105	29*	C CONN IS A CONSTANT GIVEN AS -M*G/RO WHERE M IS MASS AND G AND RO ARE AS ABOVE
00105	30*	C
00105	31*	C*****
00105	32*	C

```

00105 33* C THE FOLLOWING IS AN EXAMPLE OF A CALLING PROGRAM FOR MODATH AND PATH
00105 34* C DIMENSION ANS(35)
00105 35* C COMMON ANS
00105 36* C XLAMDA=.6
00105 37* C ZS=20.0
00105 38* C PHIS=30.0
00105 39* C THETAS=90.0
00105 40* C ZL=0.0
00105 41* C PHIL=30.0
00105 42* C THETAL=90.0
00105 43* C CALL PATH (XLAMDA,ZS,PHIS,THETAS,ZL,PHIL,THETAL)
00105 44* C WRITE (6,3) (ANS(K),K=21,23)
00105 45* C 3 FORMAT (1X,///,1X,1P3E14.4)
00105 46* C TEST=4HPRES
00105 47* C DO 1 I=1,20
00105 48* C Z=I
00105 49* C PP=1000.0-Z*50.
00105 50* C CALL MODATH (Z,PP,TEST,XLAMDA)
00105 51* C 1 WRITE (6,2) TEST,Z,(ANS(N),N=1,24)
00105 52* C 2 FORMAT (1X,A4,4X,1P12E9.3,/,1P13E9.3,/)
00105 53* C CALL EXIT
00105 54* C END
00105 55* C
00105 56* C*****
00105 57* C
00115 58* CT=288.15/273.16+1.0
00115 59* C CT IS 1.0 + RATIO OF SURFACE TEMPERATURE TO ICE TEMPERATURE
00116 60* IF (ANS(1).GE.0.0) GO TO 15
00120 61* ANS(1)=0.0
00121 62* CALL INPUT (P,T,TD,H,TV,M)
00122 63* 15 IF (TEST.EQ.4HPRES) GO TO 7
00124 64* HA= RE*Z/(RE+Z)*1000.0
00124 65* C HA IS GEOPOTENTIAL ALTITUDE IN METERS
00125 66* 23 DO 11 I=1,M
00130 67* I1=I
00131 68* IF (H(I1)-HA) 11,12,13
00134 69* 11 CONTINUE
00136 70* 9 CALL ATMOS3(Z)
00137 71* ANS(9)=0.0
00140 72* GO TO 52
00141 73* 13 I=I1-1
00142 74* DH=H(I1)-H(I)
00143 75* D=(TV(I1)-TV(I))/DH

```

00144	76*	$W = (T(I+1) - T(I)) / DH$
00145	77*	$DW = (TD(I+1) - TD(I)) / DH$
00146	78*	$DH = H(I) - HA$
00146	79*	C
00146	80*	C
00146	81*	C
00146	82*	C HEIGHT 'H' IS IN METERS
00146	83*	C HEIGHT 'Z' IS IN KM
00146	84*	C
00146	85*	C ANS(1) IS PRESSURE
00146	86*	C PRESSURE IS IN MB
00146	87*	C
00146	88*	C ANS(2) IS TEMPERATURE
00146	89*	C TEMPERATURE IS IN DEG KELVIN
00146	90*	C
00146	91*	C ANS(3) IS DENSITY
00146	92*	C DENSITY IS IN GM/CC
00146	93*	C
00146	94*	C ANS(4) IS SPEED OF SOUND
00146	95*	C SPEED OF SOUND IS IN M/SEC
00146	96*	C
00146	97*	C ANS(5) IS ACCELERATION OF GRAVITY
00146	98*	C ACCELERATION OF GRAVITY IS IN CM/SEC**2
00146	99*	C
00146	100*	C ANS(6) IS VIRTUAL TEMPERATURE
00146	101*	C TEMPERATURE IS IN DEG KELVIN
00146	102*	C
00146	103*	C ANS(7) IS MOLECULAR WEIGHT
00146	104*	C
00146	105*	C ANS(8) IS COEFFICIENT OF VISCOSITY
00146	106*	C VISCOSITY IS IN KG / (M SEC)
00146	107*	C
00146	108*	C ANS(9) IS DEW POINT TEMPERATURE
00146	109*	C TEMPERATURE IS IN DEG KELVIN
00146	110*	C
00146	111*	C ANS(10) IS MIXING RATIO R
00146	112*	C MIXING RATIO IS IN PARTS/THOUSAND I.E. (U/DO) GM/KG
00146	113*	C
00146	114*	C ANS(11) IS SATURATION MIXING RATIO RS
00146	115*	C SATURATION MIXING RATIO IS IN PARTS/THOUSAND I.E. (U/DO) GM/KG
00146	116*	C
00146	117*	C ANS(12) IS RELATIVE HUMIDITY

00146	118*	C	RELATIVE HUMIDITY IS IN PERCENT (0/0)
00146	119*	C	
00146	120*	C	ANS(13) IS SPECIFIC HUMIDITY
00146	121*	C	SPECIFIC HUMIDITY IS IN GM/KG
00146	122*	C	
00146	123*	C	ANS(14) IS SATURATION SPECIFIC HUMIDITY
00146	124*	C	SATURATION SPECIFIC HUMIDITY IS IN GM/KG
00146	125*	C	
00146	126*	C	ANS(15) IS PRESSURE SCALE HEIGHT
00146	127*	C	PRESSURE SCALE HEIGHT IS IN KM
00146	128*	C	
00146	129*	C	ANS(16) IS DENSITY SCALE HEIGHT
00146	130*	C	DENSITY SCALE HEIGHT IS IN KM
00146	131*	C	
00146	132*	C	ANS(17) IS REFRACTIVE INDEX DEVELOPED BY EDLEN IN TERMS OF WAVELENGTH ALONE
00146	133*	C	INDEX IS FOR AIR AT 288 DEG KELVIN AND 760MM HG
00146	134*	C	
00146	135*	C	ANS(18) IS REFRACTIVE INDEX DEVELOPED BY PENNDORF IN TERMS OF
00146	136*	C	WAVELENGTH, TEMPERATURE, AND PRESSURE
00146	137*	C	
00146	138*	C	ANS(19) IS THE WATER VAPOR PRESSURE IN MB
00146	139*	C	
00146	140*	C	ANS(20) IS THE SATURATION WATER VAPOR PRESSURE IN MB
00146	141*	C	
00146	142*	C	ANS(21) IS THE ZENITH ANGLE FROM GROUNDSTATION IN RADIANS
00146	143*	C	
00146	144*	C	ANS(22) = THE TOTAL GM/CM**2 OR COLUMNAR MASS ALONG THE SLANT PATH.
00146	145*	C	
00146	146*	C	ANS(23) = TOTAL GM/CM**2 OF WATER VAPOR ALONG THE SLANT PATH. IT IS
00146	147*	C	EQUIVALENT TO PRECIPITABLE CM OF WATER
00146	148*	C	
00146	149*	C	ANS(24) = TOTAL PATH LENGTH IN CM
00146	150*	C	
00146	151*	C	ANS(21) THRU ANS(24) ARE CALCULATED IN SUBROUTINE PATH.
00146	152*	C	
00146	153*	C	*****
00146	154*	C	
00147	155*		ANS(2)=T(1)-W*DH
00150	156*		ANS(6)=TV(1)-U*DH
00151	157*		ANS(9)=TD(1)-DW*DH
00152	158*		ANS(1)=PRES(P(1),D,TV(1),ANS(6),DH)
00153	159*		GO TO 14

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00154 160*      12 I=11
00155 161*      ANS(1)=P(1)
00156 162*      ANS(2)=T(1)
00157 163*      ANS(6)=TV(1)
00160 164*      ANS(9)=TD(1)
00161 165*      14 ANS(5)=G*(RE/(RE+Z))**2
00162 166*      ANS(3)=ANS(1)*XMO/(RO*ANS(6))*1000.0
00163 167*      ANS(4)=SQRT(1.4*RO*ANS(6)/XMO)/100.0
00164 168*      ANS(7)=XMO*ANS(2)/ANS(6)
00165 169*      ANS(8)=BETA*(SQRT(ANS(2)))*3/(ANS(2)+S)
00166 170*      52 ANS(19)=E(ANS(9))
00167 171*      ANS(20)=E(ANS(2))
00170 172*      ANS(10)=R(ANS(19),ANS(1),ANS(2))
00171 173*      ANS(11)=R(ANS(20),ANS(1),ANS(2))
00172 174*      ANS(12)=(ANS(10)/ANS(11))*100.0
00173 175*      ANS(13)=Q(ANS(1),ANS(9))
00174 176*      ANS(14)=Q(ANS(1),ANS(2))
00175 177*      ANS(15)=RO*ANS(6)/(XMO*ANS(5))*1.0E-05
00176 178*      ANS(16)=ANS(15)/(1.0+RO/(XMO*ANS(5))*0.01)
00177 179*      IF (XLAMDA.GE.12500.00) GO TO 30
00177 180*      C THIS MEANS IF XLAMDA IS .GE. 1.25 CM USE MICROWAVE REFRACTIVITY
00201 181*      ANS(17)=1.0+1.0E-08*(6432.8+2949810./(146.-1./(XLAMDA**2))+25540./
00201 182*      1(41.-1./(XLAMDA**2)))
00202 183*      ANS(18)=1.0+(ANS(17)-1.0)*(CT/(1.0+ANS(2)/273.16))*ANS(1)/1013.25
00203 184*      GO TO 31
00204 185*      30 ANS(18)=1.0+1.0E-06*(77.6*ANS(1)/(ANS(2))+373000.0*ANS(19)/ANS(2
00204 186*      1)**2))
00205 187*      ANS(17)=ANS(18)
00206 188*      31 RETURN
00207 189*      7 DO 16 I=1,M
00207 190*      C PRESSURE
00212 191*      I=I
00213 192*      IF (PP-P(I)) 16,41,17
00216 193*      16 CONTINUE
00220 194*      HA=0.0
00221 195*      DHA=100.0
00222 196*      51 DO 48 I=1,11
00225 197*      HA=HA+DHA
00226 198*      CALL ATMOS3(HA)
00227 199*      IF (ANS(1).LE.0.0) GO TO 42
00231 200*      IF (ANS(1).LT. PP) GO TO 49
00233 201*      48 CONTINUE
00235 202*      42 DO 10 I=2,35
00240 203*      IF (1.EQ.21.OR.1.EQ.22.OR.1.EQ.23.OR.1.EQ.24) GO TO 10
00242 204*      ANS(1)=0.0
00243 205*      10 CONTINUE

```

00245	206*	ANS(17)=1.0
00246	207*	ANS(18)=1.0
00247	208*	Z=HA
00250	209*	RETURN
00251	210*	41 Z=H(11)*RE/(1000.0*(RE-H(11)/1000.0))
00252	211*	GO TO 12
00253	212*	49 IF (ABS(ANS(1)-PP) .LE. (.001*PP)) GO TO 50
00255	213*	HA=HA-DHA
00256	214*	DHA=DHA/10.0
00257	215*	GO TO 51
00260	216*	50 Z=HA
00261	217*	GO TO 9
00262	218*	17 I=I-1
00263	219*	D=TV(I+1)-TV(I)
00264	220*	IF(D) 20,21,20
00267	221*	20 D=CONN/ALOG(P(I+1)/P(I))*ALOG(TV(I+1)/TV(I))
00270	222*	ANS(6)=TV(I)*(PP/P(I))*D/CONN
00271	223*	HA=H(I)+(ANS(6)-TV(I))/D
00272	224*	GO TO 22
00272	225*	C-HA IS IN METERS
00273	226*	21 HA=H(I)+TV(I)*ALOG(PP/P(I))/CONN
00274	227*	22 Z=HA*RE/(1000.0*(RE-HA/1000.0))
00275	228*	GO TO 23
00276	229*	END

END OF UNIVAC 1108 FORTRAN V COMPILATION. 0 *DIAGNOSTIC* MESSAGE(S)

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00101 1* SUBROUTINE ATMOS3 (Z)
00101 2* C SUBROUTINE FOR THE 1962 STANDARD
00101 3* C Z IS ALTITUDE IN KM
00103 4* DIMENSION H(23),T(23),P(23),ANS(35),A(23),ZZ(23)
00104 5* COMMON ANS
00105 6* DATA H/-5000.,0.0,11000.0,20000.0,32000.0,47000.0,52000.0,61000.0,
00105 7* 179000.,88744.2,98452.,108129.8,117777.7,146543.8,156073.6,165574.3
00105 8* 2,184488.55,221972.686,286486.49,376331.361,463556.85,548275.86,
00105 9* 2630594.90,1,1/320.65
00105 10* 3,288.15,216.65,216.65,228.65,270.65,270.65,252.65,180.65,180.65,
00105 11* 4210.65,260.65,360.65,960.65,1110.65,1210.65,1350.65,1550.65,1830.6
00105 12* 55,2160.65,2420.65,2590.65,2700.65, P/1.77687E+03,1.01325E+03,
00105 13* 62.26320E+02,5.47487E+01,8.68014,1.10905,5.90005E-01,1.82099E-01,
00105 14* 71.0377E-02,1.6438E-03,3.0075E-04,7.3544E-05,2.5217E-05,5.0617E-06,
00105 15* 83.6943E-06,2.7926E-06,1.6852E-06,6.9604E-07,1.8838E-07,4.0304E-08,
00105 16* 91.0957E-08,3.4502E-09,1.1918E-09, A/320.650,
00105 17* 1 288.15,216.65,216.65,228.65,270.65,270.65,252.65,180.65,180.65,
00105 18* 2 210.02,257.0,349.49,892.79,1022.2,1105.5,1205.5,1321.7,1432.1,
00105 19* 3,1487.4,1499.2,1506.1,1507.6, ZZ/ -5000.,0.0,11000.,20000.,32000.,
00105 20* 447000.,52000.,61000.,79000.,90000.,100000.,110000.,120000.,150000.
00105 21* 5,160000.,170000.,190000.,230000.,300000.,400000.,500000.,600000.,
00105 22* 6700000./
00113 23* DATA S/110.4/,CONN/-3.41631947E-02/,RE/6.36E+06/
00113 24* C
00113 25* C*****
00113 26* C
00113 27* C Z4 IS THE GEOMETRIC ALTITUDE FOR BREAKPOINTS ABOVE 90 KM
00113 28* C H(1) IS THE ALT IN GEOPOTENTIAL METERS FOR SIGNIFICANT LEVELS
00113 29* C D IS THE TEMPERATURE GRADIENT IN THE VERTICAL (DEG/GEOPM)
00113 30* C T(1) IS THE MOLECULAR SCALE TEMPERATURE AT A SIGNIFICANT LEVEL
00113 31* C A(1) IS THE KINETIC TEMPERATURE AT THE SIGNIFICANT LEVELS
00113 32* C P(1) IS THE PRESSURE IN LB/FT**2. ACTUALLY IT WONT MATTER AND PRESSURE CAN
00113 33* C BE IN ANY SET OF UNITS SINCE ONLY THE RATIO AT VARIOUS ALTITUDES RELATIVE
00113 34* C TO P(2) IS USED
00113 35* C ANS(1) IS THE RATIO OF PRESSURES (P/PSL)
00113 36* C ANS(1)*1.01325E+03 FOR PRES IN MB
00113 37* C ANS(2) IS THE RATIO OF TEMPERATURE (T/ISL)
00113 38* C ANS(2)*288.15 FOR TEMP IN DEG K
00113 39* C ANS(3) IS THE RATIO OF DENSITIES
00113 40* C ANS(3)*1.225E-03 FOR DENSITY IN GM/CC
00113 41* C ANS(4) IS THE RATIO OF SPEED OF SOUND (C/CSL)
00113 42* C ANS(4)*340.294 FOR SPEED OF SOUND IN M/SEC
00113 43* C ANS(5) IS THE ACCELERATION OF GRAVITY (G/GSL)

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00113 44* C ANS(5)=980.665 FOR ACC UP GRAVITY IN CM/(SEC**2)
00113 45* C ANS(6) IS THE RATIO QS MOLECULAR SCALE TEMPERATURE
00113 46* C ANS(6)=288.15 FOR TEMP IN DEG K
00113 47* C ANS(7) IS THE MOLECULAR WEIGHT
00113 48* C ANS(8) IS THE RATIO OF COEF OF VISCOSITY (MU/MUSL)
00113 49* C ANS(8)=1.7894E-05 TO COEF IN KM/M-SEC
00113 50* C W IS THE VERTICAL KINETIC TEMPERATURE GRADIENT
00113 51* C THIS RADIUS 'RE' IS CHOSEN TO AGREE WITH THE U S STANDARD AT 40 KM, BUT IT
00113 52* C ALSO IS A BEST FIT TO ALL LEVELS BELOW 90 KM. ABOVE 90 KM THE LEVELS
00113 53* C THAT ARE BREAK POINTS WERE CALCULATED FROM GEOMETRIC TO GEOP USING 'RE'
00113 54* C
00113 55* C*****
00113 56* C
00117 57* Z=Z*1000.0
00120 58* IF (Z-700000.0) 10,50,50
00123 59* 10 CONTINUE
00124 60* HA=RE*Z/(RE+Z)
00125 61* ANS(5)=RE**2/((RE+Z)**2)
00126 62* DO 1 M=1,23
00131 63* I=M
00132 64* IF (H(I)-HA) 1,2,3
00135 65* 1 CONTINUE
00137 66* GO TO 50
00140 67* 3 I=I-1
00141 68* D=(T(I+1)-T(I))/(H(I+1)-H(I))
00142 69* W=(A(I+1)-A(I))/(H(I+1)-H(I))
00143 70* GO TO 4
00144 71* 2 ANS(6)=T(I)/T(2)
00145 72* ANS(2)=A(I)/A(2)
00146 73* D=(T(I+1)-T(I))/(H(I+1)-H(I))
00147 74* GO TO 5
00150 75* 4 IF (90000.0-Z) 7,7,9
00153 76* 7 ANS(6)=(T(I)-(T(I+1)-T(I))/(ZZ(I+1)-ZZ(I))*(ZZ(I)-Z))/T(2)
00154 77* ANS(2)=(A(I)-(A(I+1)-A(I))/(ZZ(I+1)-ZZ(I))*(ZZ(I)-Z))/A(2)
00155 78* GO TO 5
00156 79* 9 ANS(6)=(T(I)-D*(H(I)-HA))/T(2)
00157 80* ANS(2)=(A(I)-W*(H(I)-HA))/A(2)
00160 81* 5 IF (90000.0-Z) 8,6,6
00163 82* 6 ANS(7)=28.9644
00164 83* GO TO 11
00165 84* 8 ANS(7)=28.9644*ANS(2)/ANS(6)
00166 85* 11 ANS(4)=SQRT(ANS(6))

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00167      86*      ANS(8)=((T(2)+S)/(ANS(2)*T(2)+S))*SQRT((ANS(2))**3)
00170      87*      IF (D) 12,13,12
00173      88*      12 CONN=D*ALOG(P(I+1)/P(I))/(ALOG(T(I+1)/T(I)))
00174      89*      ANS(1)=P(I)/P(2)*(ANS(6)*T(2)/T(I))*-(CONN/D)
00175      90*      GO TO 14
00176      91*      13 CONN=ALOG(P(I+1)/P(I))/(H(I+1)-H(I))*T(I)
00177      92*      ANS(1)=P(I)/P(2)* EXP(CONN*((HA-H(I))/(ANS(6)*T(2))))
00200      93*      14 ANS(3)=ANS(1)/ANS(6)
00201      94*      ANS(1)=ANS(1)*1.01325E+03
00202      95*      ANS(2)=ANS(2)*288.15
00203      96*      ANS(3)=ANS(3)*1.225E-03
00204      97*      ANS(4)=ANS(4)*340.294
00205      98*      ANS(5)=ANS(5)*980.665
00206      99*      ANS(6)=ANS(6)*288.15
00207     100*      ANS(8)=ANS(8)*1.7894E-05
00210     101*      Z=Z/1000.0
00211     102*      GO TO 53
00212     103*      50 DO 51 I=1,8
00215     104*      51 ANS(I)=0.0
00217     105*      53 RETURN
00220     106*      END

```

END OF UNIVAC 1108 FORTRAN V COMPILATION.

0 *DIAGNOSTIC* MESSAGE(S)

```

00101 1* SUBROUTINE INPUT (P,T,TD,H,TV,M)
00102 2* DIMENSION P(1),T(1),TD(1),H(1),TV(1)
00103 3* C
00103 4* C*****
00103 5* C
00103 6* C THIS INPUT SUBROUTINE IS SET UP TO TAKE STANDARD PRINTOUT OF CODE VV ,
00103 7* C (IE SIGNIFICANT LEVELS OF A RADIOSONDE) AND SET ALTITUDES, VIRTUAL TEMP,
00103 8* C DEWPOINT TEMPERATURES, AND AMBIENT TEMPERATURES OR IF A BLANK CARD
00103 9* C PRECEEDS THE DATA THE INPUT DATA IS OF THE FORM HEIGHT, PRESSURE,
00103 10* C TEMPERATURE, AND RELATIVE HUMIDITY
00103 11* C
00103 12* C*****
00103 13* C
00104 14* CONDE=5H
00105 15* NSATI=5H
00106 16* ON=5H
00107 17* M=0
00110 18* H(1)=0.0
00111 19* WRITE (6,25)
00113 20* 25 FORMAT (1X,41X,'EARTH RESOURCES MODEL ATMOSPHERE,1969',
00113 21* 1,/, 29X,'THE SIGNIFICANT LEVELS FOR THE MODEL ATMOSPHERE
00113 22* 2ARE AS FOLLOWS: ',/,34X,'ALT:',10X,'PRES:',10X,'TEMP:',9X,'TD:',11X
00113 23* 3,'TV',/,34X,'(M)',10X,'(MB)',10X,'(K)',10X,'(K)',10X,'(K)',/)
00113 24* C
00113 25* C*****
00113 26* C
00113 27* C THIS SECTION INPUTS CODED DATA
00113 28* C
00114 29* DO 1 I=1,25
00117 30* READ(5,3) P(I),T(I),TD(I)
00117 31* C THIS IS THE FORMAT FOR READING RADIOSONDE DATA
00124 32* 3 FORMAT(1X,F3.0,1X,F3.0,F2.0)
00124 33* C ALTITUDE IN METERS
00124 34* C PRESSURE IN MB
00124 35* C T AND TD IN DEG KELVIN
00125 36* IF (P(I).LE.0.0.AND.T(I).LE.0.0.AND.TD(I).LE.0.0) GO TO 11
00127 37* IF (P(I).LE.0.0) GO TO 2
00131 38* M=M+1
00132 39* IF(I.EQ.1.AND.P(I).LT.1000.0) P(I)=P(I)+1000.0
00134 40* IF (AMOD(T(I),2.0).GT.0.0) T(I)=-T(I)
00136 41* T(I)=T(I)*.1
00137 42* IF (TD(I).GT.0.01.AND.TD(I).LE.50.0) TD(I)=TD(I)*.1
00141 43* IF(TD(I).GE.51.0.AND.TD(I).LE.55.0) WRITE(6,4)
00144 44* 4 FORMAT(1X,'INVALID TD INPUT DATA')

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00145 45*      IF (TD(I) .GE. 56.0 .AND. TD(I) .LE. 99.0) TD(I)=TD(I)-50.0
00147 46*      IF (TD(I) .LE. .01) TD(I)=T(I)+273.16
00151 47*      TD(I)=T(I)-TD(I)
00152 48*      T(I)=T(I)+273.16
00153 49*      TD(I)=TD(I)+273.16
00154 50*      1 CONTINUE
00156 51*      GO TO 2
00156 52*      C
00156 53*      C*****
00156 54*      C
00156 55*      C THIS SECTION INPUTS NON-CODED DATA
00156 56*      C
00157 57*      11 M=0
00160 58*      DO 12 I=1,25
00160 59*      C THIS IS THE FORMAT FOR READING SIGNIFICANT LEVELS IN NON-CODED FORM
00163 60*      READ (5,13) H(I),P(I),T(I),TD(I)
00171 61*      13 FORMAT (E9.3,E12.6,F7.2,F3.0)
00171 62*      C TD(I) HERE, IS RELATIVE HUMIDITY UNTIL A TD(I) IS FOUND BY ITERATION
00172 63*      DELT=100.0
00173 64*      GUESS=50.0
00174 65*      RI=R(E(T(I)),P(I),T(I))
00175 66*      992 DO 990 L=1,11
00200 67*      GUESS=GUESS+DELT
00201 68*      REL=R(E(GUESS),P(I),GUESS)*100.0/RI
00202 69*      Q=REL-TD(I)
00203 70*      IF (Q) 990,991,995
00206 71*      990 CONTINUE
00210 72*      CALL EXIT
00211 73*      995 GUESS=GUESS-DELT
00212 74*      DELT=DELT/10.0
00213 75*      991 IF (ABS(Q) .GT. .01) GO TO 992
00215 76*      TD(I)=GUESS
00216 77*      IF (P(I) .LE. 0.0) GO TO 2
00220 78*      M=M+1
00221 79*      12 CONTINUE
00221 80*      C
00221 81*      C*****
00221 82*      C
00223 83*      2 DO 5 I=1,M
00226 84*      IF (TD(I) .LE. 0.0) GO TO 7
00230 85*      TV(I)=T(I)/(1.0-(0.37803*E(TD(I))*F(P(I),T(I))/P(I)))
00231 86*      GO TO 5
00232 87*      7 TV(I)=T(I)
00233 88*      5 CONTINUE

```

00235	89*	DO 26 I=M,25
00240	90*	H(I)=H(M)
00241	91*	26 P(I)=P(M)
00243	92*	DO 6 I=1,M
00246	93*	IF (ABS(T(I)-TD(I))*GT.1.0+H(I)*.000777) GO TO 27
00250	94*	CONDE=5HCONDE
00251	95*	NSATI=5HNSATI
00252	96*	QN=5HQN
00253	97*	27 WRITE (6,24) H(I),P(I),T(I),TD(I),TV(I),CONDE,NSATI,QN
00265	98*	24 FORMAT (26X,1P2E13.3,0P3F13.2,1X,3A5)
00266	99*	IF (CONDE.EQ.5H) GO TO 6
00270	100*	CONDE=5H
00271	101*	NSATI=5H
00272	102*	QN=5H
00273	103*	6 CONTINUE
00275	104*	WRITE (6,86)
00277	105*	86 FORMAT (//)
00300	106*	RETURN
00301	107*	END

END OF UNIVAC 1108 FORTRAN V COMPILATION.

0 *DIAGNOSTIC* MESSAGE(S)

```

00101      1*      SUBROUTINE REFRAC (Z1,Z2,XLAMDA,PHI,PHIPR,PSI,SLANT)
00103      2*      DIMENSION ANS(35)
00104      3*      COMMON ANS
00105      4*      DATA RE/6371.299/
00105      5*      C
00105      6*      C*****
00105      7*      C
00105      8*      C IN ORDER TO CALCULATE A CONTINUOUS PATH YOU MUST EXTERNALLY SET PHI=PHIPR
00105      9*      C Z1, Z2, PHI, AND XLAMDA ARE INPUT VARIABLES
00105     10*      C Z1 AND Z2 ARE IN KM AND XLAMDA IS IN MICRONS
00105     11*      C PHIPR, PSI, AND SLANT ARE OUTPUT VARIABLES
00105     12*      C PHI, PHIPR, AND PSI ARE IN RADIANS AND SLANT IS IN CM
00105     13*      C IF YOU WANT AMOUNT OF GM/CM**2 (COLUMNAR MASS) OF ATMOSPHERE FROM Z1 TO Z2
00105     14*      C USE ANS(3)*SLANT. GM/CM**2 OF WATER IS ANS(3)*SLANT*ANS(13)/1000.0.
00105     15*      C SINCE ALL ANS ARRAY IS IN COMMON, YOU CAN DO THIS EXTERNALLY.
00105     16*      C
00105     17*      C*****
00105     18*      C
00107     19*      S1=RE+Z1
00110     20*      S2=RE+Z2
00111     21*      DELT=(Z2-Z1)/2.0
00112     22*      CALL MODATM(Z2+DELT,PP,4HALTI,XLAMDA)
00113     23*      DZ=ANS(3)
00114     24*      XN2=ANS(18)
00115     25*      CALL MODATM(Z1+DELT,PP,4HALTI,XLAMDA)
00116     26*      D1=ANS(3)
00117     27*      XN1=ANS(18)
00120     28*      PSI=SININV(S1*SIN(PHI)/S2)
00121     29*      PHIPR=SININV(S1*SIN(PHI)*XN1/(S2*XN2))
00122     30*      SLANT=S1*SIN(PHI-PSI)/SIN(PSI)*1.0E+05
00123     31*      RETURN
00124     32*      END

```

END OF UNIVAC 1108 FORTRAN V COMPILATION.

0 *DIAGNOSTIC* MESSAGE(S)

```

00101 1* SUBROUTINE PATH (XLAMDA,ZS,PHIS,THEIAS,ZL,PHIL,THETAL)
00103 2* DIMENSION ANS(35),A(3,3),B(3),C(3)
00104 3* COMMON ANS
00105 4* DATA PI/3.14159265/,CON/.0174532925/,RE/6371.299/
00105 5* C
00105 6* C*****
00105 7* C
00105 8* C QUANTITIES ENDING IN S ARE FOR THE SATELLITE
00105 9* C QUANTITIES ENDING IN L ARE FOR THE GROUND LOCAL
00105 10* C -Q1- AND -Q2- ARE DUMMY VARIABLES
00105 11* C -XS, YS, AND HS- ARE THE RECTANGULAR COORDINATES OF THE SPACECRAFT
00105 12* C -XL, YL, AND HL- ARE THE RECTANGULAR COORDINATES OF THE GROUND LOCAL
00105 13* C THE ANGLE ABD IS THE ANGLE BETWEEN THE SUBSATELLITE POINT AND TARGET.
00105 14* C ANGLE ABD IS FOUND BY USING THE DOT PRODUCT AND TAKING THE INVERSE COS
00105 15* C .0092833 RADIANS IS THE TOTAL REFRACTION ON A PASS THRU U.S. STANDARD
00105 16* C 'SUM1' IS THE TOTAL ANGLE CHANGE DURING REFRACTION
00105 17* C 'SUM1' IS THE SUM OF ALL DELTA XI CALCULATED BY LAW OF SINES
00105 18* C 'SUM2' IS PRECIPITABLE CM OF WATER OR GM/CM**2 OF WATER VAPOR
00105 19* C 'SUM3' IS THE TOTAL COLUMNAR MASS IN THE SLANT PATH
00105 20* C 'SUM4' IS THE TOTAL SLANT PATH IN CM
00105 21* C PHI IS IN RADIANS
00105 22* C
00105 23* C ANS(21) IS THE ZENITH ANGLE FROM GROUNDSTATION IN RADIANS
00105 24* C
00105 25* C ANS(22) = THE TOTAL GM/CM**2 OR COLUMNAR MASS ALONG THE SLANT PATH,
00105 26* C
00105 27* C ANS(23) = TOTAL GM/CM**2 OF WATER VAPOR ALONG THE SLANT PATH, IT IS
00105 28* C EQUIVALENT TO PRECIPITABLE CM OF WATER.
00105 29* C
00105 30* C ANS(24) = TOTAL PATH LENGTH IN CM
00105 31* C
00105 32* C*****
00105 33* C
00111 34* PHIS=PHIS*CON
00112 35* THETAS=THETAS*(-CON)
00113 36* PHIL=PHIL*CON
00114 37* THETAL=THETAL*(-CON)
00115 38* DELT=ABS(ZL-ZS)
00116 39* DO 80 I=1,32000
00121 40* DELT=DELT/10.0
00122 41* L=I
00123 42* IF(DELT.LE.2.0) GO 10 81
00125 43* 80 CONTINUE
00127 44* CALL EXIT

```

```

00130 45*      81 IF (L.LE.1) DELT=DELT/10.0
00132 46*      ANS(1)=-1.0
00133 47*      Q1=RE+ZS
00134 48*      Q2=COS(PHIS)
00135 49*      XS=Q1*COS(THETAS)*Q2
00136 50*      YS=Q1*SIN(THETAS)*Q2
00137 51*      HS=Q1*SIN(PHIS)
00140 52*      Q2=COS(PHIL)
00141 53*      Q1=RE+ZL
00142 54*      XL=Q1*COS(THETAL)*Q2
00143 55*      YL=Q1*SIN(THETAL)*Q2
00144 56*      HL=Q1*SIN(PHIL)
00145 57*      ABD=COSINV(((XS*XL)+(YS*YL)+(HS*HL))/(SQRT(XS**2+YS**2+HS**2)
00145 58*      1*SQRT(XL**2+YL**2+HL**2)))
00146 59*      DO 3 I=1,3
00151 60*      3 C(I)=0.0
00151 61*      C FROM HERE TO STATEMENT 4 FINDS THE VECTOR (C) FROM THE TARGET TO THE
00151 62*      C SATELLITE
00153 63*      A(1,1)=SIN(PHIL)*COS(THETAL)
00154 64*      A(2,1)=-SIN(THETAL)
00155 65*      A(3,1)=COS(PHIL)*COS(THETAL)
00156 66*      A(1,2)=SIN(PHIL)*SIN(THETAL)
00157 67*      A(2,2)=COS(THETAL)
00160 68*      A(3,2)=COS(PHIL)*SIN(THETAL)
00161 69*      A(1,3)=-COS(PHIL)
00162 70*      A(2,3)=0.0
00163 71*      A(3,3)=SIN(PHIL)
00164 72*      B(1)=XS-XL
00165 73*      B(2)=YS-YL
00166 74*      B(3)=HS-HL
00167 75*      DO 4 I=1,3
00172 76*      DO 4 M=1,3
00175 77*      4 C(I)=A(I,M)*B(M)+C(I)
00200 78*      PHIL=PHIL/CON
00201 79*      THETAL=THETAL/(-CON)
00202 80*      PHIS=PHIS/CON
00203 81*      THETAS=THETAS/(-CON)
00204 82*      PHI=ATAN2(SQRT(C(1)**2+C(2)**2),C(3))
00205 83*      IF (PHI.GT..017)PHI=PHI-.0092833
00207 84*      IF (PHI/CON.GT.90.0)WRITE (6,88)
00212 85*      88 FORMAT (///.1X,'WARNING,ZENITH ANGLE OF UNREFRACTED PATH EXCEEDS
00212 86*      190.0 DEG',.1X,'IT IS HIGHLY PROBABLE THAT THE AIRCRAFT OR SPACE
00212 87*      2CRAFT CANNOT SEE THE TARGET',///)
00213 88*      89 CALL MODATM (ZL+DELT*.5,PP,4HALTI,XLAMDA)

```

00214	89*	PHIINT=PHI
00215	90*	Z1=ZL
00216	91*	D1=ANS(3)
00217	92*	WATER1=ANS(13)
00220	93*	XN1=ANS(18)
00221	94*	SUM=0.0
00222	95*	SUM1=0.0
00223	96*	SUM2=0.0
00224	97*	SUM3=0.0
00225	98*	SUM4=0.0
00226	99*	DO 1 I=1,32000
00231	100*	Z2=Z1+DELT
00232	101*	S1=RE+Z1
00233	102*	S2=RE+Z2
00234	103*	CALL MODATM (Z2+DELT*.5,PP,4HALTI,XLAMDA)
00235	104*	D2=ANS(3)
00236	105*	WATER2=ANS(13)
00237	106*	XN2=ANS(18)
00240	107*	PSI=SININV(S1*SIN(PHI)/S2)
00241	108*	PHIPR=SININV(S1*SIN(PHI)*XN1/(S2*XN2))
00242	109*	DUM=D1*S1*SIN(PHI-PSI)/SIN(PSI)*1.0E+05
00243	110*	SUM1=SUM1+PHI-PSI
00244	111*	SUM2=SUM2+WATER1*DUM/1000.0
00245	112*	SUM3=SUM3+DUM
00246	113*	SUM4=SUM4+DUM/D1
00247	114*	IF (Z2-GE-ZS) GO TO 82
00251	115*	SUM=SUM+ABS(PHIPR-PSI)
00252	116*	PHI=PHIPR
00253	117*	Z1=Z2
00254	118*	D1=D2
00255	119*	WATER1=WATER2
00256	120*	1 XN1=XN2
00260	121*	CALL EXIT
00261	122*	82 CONTINUE
00262	123*	Q=SUM1-ABD
00263	124*	PHI=PHIINT-Q/2.0
00264	125*	IF (ABS(Q)-GE-.0001) GO TO 89
00266	126*	ANS(21)=PHI
00267	127*	ANS(22)=SUM3
00270	128*	ANS(23)=SUM2
00271	129*	ANS(24)=SUM4
00272	130*	IF (PHI/CON-LE.90.0) GO TO 83
00274	131*	WRITE (6,87)
00276	132*	87 FORMAT (1X,///,1X,' THE ANGLE FROM ZENITH IS GREATER THAN 90.0')

00277	133*	ANS(22)=0.0
00300	134*	ANS(23)=0.0
00301	135*	ANS(24)=0.0
00302	136*	83. RETURN
00303	137*	END

END OF UNIVAC 1108 FORTRAN V COMPILATION.

0 *DIAGNOSTIC* MESSAGE(S)

```

00101      1*      FUNCTION COSINV(A)
00101      2*      C THIS FUNCTION CALCULATES THE INVERSE COSINE OF 'A'.
00103      3*      COSINV=ATAN2(SQRT(1.0-A**2),A)
00104      4*      RETURN
00105      5*      END

```

END OF UNIVAC 1108 FORTRAN V COMPILATION, 0 *DIAGNOSTIC* MESSAGE(S)

```

00101      1*      FUNCTION SININV(A)
00101      2*      C THIS FUNCTION CALCULATES THE INVERSE SINE OF 'A'.
00103      3*      SININV=ATAN2(A,(SQRT(1.0-A**2)))
00104      4*      RETURN
00105      5*      END

```

END OF UNIVAC 1108 FORTRAN V COMPILATION, 0 *DIAGNOSTIC* MESSAGE(S)

```

00101      1*      FUNCTION Q(P,T)
00101      2*      C Q = SPECIFIC HUMIDITY WITH UNITS OF GM/KG
00101      3*      C SPECIFIC HUMIDITY=GM OF WATER VAPOR / (KG OF AIR,INCLUDING WATER VAPOR)
00103      4*      X=E(T)
00104      5*      Q=0.62197*X/(P-0.378Q3*X)*1000.0
00105      6*      RETURN
00106      7*      END

```

END OF UNIVAC 1108 FORTRAN V COMPILATION, 0 *DIAGNOSTIC* MESSAGE(S)

```

00101 1*      FUNCTION ALTITU (TVHIGH,TVLOW,PHIGH,PLOW,HLOW)
00101 2*      C
00101 3*      C*****
00101 4*      C
00101 5*      C GIVEN THE TEMPERATURE AND PRESSURE AT EACH OF 2 POINTS AND THE ALTITUDE OF
00101 6*      C      THE LOWER POINT, THIS FUNCTION CALCULATES THE ALTITUDE OF THE HIGHER POINT
00101 7*      C ALTITU IS IN METERS. CONN IS A CONSTANT = -M*G/R
00101 8*      C
00101 9*      C*****
00101 10*     C
00103 11*     DATA CONN/-3.41631947E-02/
00105 12*     D=TVHIGH-TVLOW
00106 13*     IF(D) 2,3,2
00111 14*     2 D=CONN/(ALOG(PHIGH/PLOW))*ALOG(TVHIGH/TVLOW)
00112 15*     ALTITU =HLOW+(TVHIGH-TVLOW)/D
00113 16*     GO TO 6
00114 17*     3 ALTITU =HLOW+TVLOW*ALOG(PHIGH/PLOW)/CONN
00115 18*     6 RETURN
00116 19*     END

```

END OF UNIVAC 1108 FORTRAN V COMPILATION. 0 *DIAGNOSTIC* MESSAGE(S)

```

00101      1*      FUNCTION PRES(PLOW,D,TVLOW,TVHIGH,DH)
00103      2*      DATA CONN/-3.41631947E-02/
00103      3*      C
00103      4*      C*****
00103      5*      C
00103      6*      C THIS PROGRAM CALCULATES PRESSURE -PRES- AT SOME POINT -DH- ABOVE A
00103      7*      C POINT IN THE ATMOSPHERE HAVING PRESSURE -PLOW- WHERE -D- IS THE
00103      8*      C TEMPERATURE GRADIENT AND -TVHIGH- AND -TVLOW- ARE CORRESPONDING
00103      9*      C TEMPERATURES. -CONN- IS CONSTANT = -M*G/R
00103     10*      C
00103     11*      C*****
00103     12*      C
00105     13*      IF (D) 2,3,2
00110     14*      2 PRES=PLOW*(TVHIGH/TVLOW)**(CONN/D)
00111     15*      GO TO 4
00112     16*      3 PRES=PLOW*EXP(-CONN*DH/TVLOW)
00113     17*      4 RETURN
00114     18*      END

```

END OF UNIVAC 1108 FORTRAN V COMPILATION. 0 *DIAGNOSTIC* MESSAGE(S)

```

00101      1*      FUNCTION E(X)
00103      2*      DATA TS/373.16/,TO/273.16/
00103      3*      C
00103      4*      C*****
00103      5*      C
00103      6*      C THIS ROUTINE CALCULATES VAPOR PRESSURE OVER A PLANE SURFACE OF
00103      7*      C WATER (C = 0.0) OR OF ICE (C = 273.16) BASED ON TEMPERATURE IN DEG
00103      8*      C KELVIN. E(X) IS IN MB
00103      9*      C SET C=273.16 IF YOU WANT VAPOR PRES OVER ICE USED BELOW 273. DEG K
00103     10*      C
00103     11*      C*****
00103     12*      C
00106     13*      C=0.0
00107     14*      T=X-C
00110     15*      IF (X.LE.1.0) GO TO 4
00112     16*      IF (T) 1,2,2
00112     17*      C FORMULA FOR VAPOR PRESSURE OVER ICE
00115     18*      1 E=6.1071*10.0**(-9.09718*(-1.0+T/X)-3.56654*LOG10(T/X)+0.876793
00115     19*      1*(1.0-X/T))
00116     20*      GO TO 5
00116     21*      C
00116     22*      C*****
00116     23*      C

```

```

00116 24* C FORMULA FOR VAPOR PRESSURE OVER WATER
00117 25* 2 E=1013.246*10.0**(-7.90298*(-1.0+TS/X)+5.02808*LOG10(TS/X)-1.3816E
00117 26* 1-07*(10.0**((1.344*(1.0-X/TS))-1.0)+8.1328E-03*(10.0**(-3.4914*(-1
00117 27* 2.0+TS/X))-1.0))
00120 28* GO TO 5
00121 29* 4 E=0.0
00122 30* 5 RETURN
00123 31* END

```

END OF UNIVAC 1108 FORTRAN V COMPILATION. 0 *DIAGNOSTIC* MESSAGE(S)

```

00101 1* FUNCTION R(S,P,X)
00101 2* C
00101 3* C*****
00101 4* C
00101 5* C THIS ROUTINE CALCULATES THE MIXING RATIO (GM OF H2O)/(KG OF DRY AIR)
00101 6* C BASED ON X WHICH IS TEMPERATURE IN DEG KELVIN
00101 7* C R(S,P,X) =0/00 (IE PARTS PER THOUSAND)
00101 8* C S IS VAPOR PRESSURE OF WATER
00101 9* C P IS TOTAL ATMOSPHERIC PRESSURE IN MB
00101 10* C
00101 11* C*****
00101 12* C
00103 13* IF (S) 7,6,7
00106 14* 7 CONTINUE
00107 15* R=18.016*S*F(P,X)/(28.9664*(P-S*F(P,X)))*1000.0
00107 16* C R IS IN GM/KG
00110 17* RETURN
00111 18* 6 R=0.0
00112 19* RETURN
00113 20* END

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END OF UNIVAC 1108 FORTRAN V COMPILATION. 0 *DIAGNOSTIC* MESSAGE(S)

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00101 1*      FUNCTION F(P,X)
00103 2*      DIMENSION TE(12),PE(11),U(12,11)
00104 3*      DATA ((U(1,J),J=1,11),I=1,12) /0.,1.,2.,3.,6.,12.,16.,30.,42.,53.,
00104 4*      165.,1.,1.,2.,3.,6.,11.,17.,27.,38.,49.,60.,1.,1.,2.,3.,6.,11.,16.,
00104 5*      226.,36.,46.,55.,1.,2.,3.,4.,6.,11.,15.,24.,34.,43.,52.,1.,2.,4.,
00104 6*      35.,7.,11.,15.,24.,32.,41.,49.,0.,2.,5.,6.,8.,12.,16.,24.,32.,40.,
00104 7*      447.,4*0.,10.,14.,18.,25.,32.,40.,47.,4*0.,12.,16.,20.,27.,34.,41.,
00104 8*      548.,6*0.,23.,30.,37.,44.,50.,6*0.,26.,34.,41.,48.,54.,7*0.,37.,45.,
00104 9*      6.,52.,59.,8*0.,48.,56.,64./,PE/-50.,-40.,-30.,-20.,-10.,0.,10.,20.,
00104 10*     730.,40.,50.,60./,PE/5.,10.,30.,50.,100.,200.,300.,500.,700.,900.,
00104 11*     81160./
00104 12* C
00104 13* C*****
00104 14* C
00104 15* C *F* IS THE CORRECTION FACTOR FOR THE DEPARTURE OF THE MIXTURE OF AIR
00104 16* C   AND WATER VAPOR FROM THE IDEAL GAS LAW.
00104 17* C X IS TEMPERATURE IN DEG KELVIN
00104 18* C P IS TOTAL ATMOSPHERIC PRESSURE IN MB
00104 19* C
00104 20* C*****
00104 21* C
00110 22*      T=X-273.16
00111 23*      DO 1 I=1,12
00114 24*      IF (T.LE.TE(I)) GO TO 2
00116 25*      I=1
00117 26*      1 CONTINUE
00121 27*      FA=1.0
00122 28*      GO TO 3
00123 29*      2 DO 4 J=1,11
00126 30*      IF (P.LE.PE(J)) GO TO 5
00130 31*      JJ=J
00131 32*      4 CONTINUE
00133 33*      FA=1.0
00134 34*      GO TO 3
00135 35*      5 I=11
00136 36*      J=JJ
00137 37*      F1=(U(I+1,J)-U(I,J))/10.0*(T-TE(I))+U(I,J)
00140 38*      F2=(U(I+1,J+1)-U(I,J+1))/10.0*(T-TE(I))+U(I,J+1)
00141 39*      FA=(F2-F1)/(PE(J+1)-PE(J))*(P-PE(J))+F1
00142 40*      FA=1.0+FA*1.0E-04
00143 41*      3 F=FA
00144 42*      RETURN
00145 43*      END

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END OF UNIVAC 1108 FORTRAN V COMPILATION.

O *DIAGNOSTIC* MESSAGE(S)